Robust Contactless Waveguide Flange for Fast Measurements

Cornelius Mayaka[*], Yonghui Shu, Dhanraj Doshi
Eravant, USA
yshu@eravant.com, fn-ddoshi@eravant.com

***Abstract*—Good electrical contact is always required between waveguide flanges of the test system and DUT to minimize leakage and losses that will degrade circuit performance. This requires the DUT to be tightly and carefully connected to avoid gaps and mismatches. This can be time consuming, especially when performing repeated measurements on multi-port devices. In this paper we present a contactless flange that can be used at millimeter-wave (mmW) and terahertz (THz) frequencies. Unlike conventional waveguide flanges, the contactless flange can be used to perform fast measurements because normal flange screws are not required. An E-band prototype has already been successfully designed, manufactured, and tested. The use of contactless waveguide flanges allows for faster, accurate, and reliable mmW and THz measurements.**

***Keywords*—Contactless waveguide flange, rail, gap waveguides, perfect electric conductor, perfect magnetic conductor, high impedance surface.**

I. Introduction

Measuring high frequency waveguide-based systems necessitates the physical interconnection of the components commonly through the usage of standard waveguide flanges and screws. The problem with high-frequency (mmW and THz) devices is that there is a strict mechanical requirement on good electrical contact between waveguide flanges, therefore the waveguide flanges must be tightly connected to each other to avoid mechanically induced interface mismatch. Gaps between the mating flanges will lead to power leakage and poor return loss causing unreliable and inaccurate measurements [1]-[2]. Additionally, frequently attaching and detaching the waveguides degrades its quality and performance and slows down testing, which can be detrimental in areas where speed is a priority.

Fig. 1. Contactless waveguide flange

[*] at the time of writing this paper, the author was with Eravant, USA

This paper covers a contactless waveguide flange (CWF) design based on gap waveguide technology and the principle of operation of the choke flange. The choke is a $\lambda g/4$ deep ring engraved in the flange, at a distance $\lambda g/4$ from the waveguide, where λg is the guide wavelength. The concepts of gap waveguide technology have been thoroughly studied and used previously in the designs of antenna array feeding structures and other passive components [3]. If a perfect magnetic conductor (PMC) plate and a perfect electric conductor (PEC) plate are placed such that they are parallel to each other and the distance between the two plates is less than $\lambda_0/4$, where λ_0 is wavelength of the operating frequency in air, a cut-off condition is created, and no parallel plate modes will propagate between the plates. One of the waveguide flanges is populated with rings of small pin-like structures to realize the high impedance surface (AMC), while the other surface is flat (PEC). Since no physical contact is required as opposed to traditional flanges, fast measurement can be easily performed due to the connection screws of the traditional flange interface no longer being required.

II. Design

A. Electrical Design

The 3D geometry of the proposed contactless flange is shown in Fig.1. A traditional E-band waveguide flange is modified by adding two circular rows of pins around the waveguide opening of the flange interface. The metal surface surrounding the waveguide opening has a width of around $\lambda g/4$ along the two long sides to transform an open circuit to a short circuit at the opening. The metal surface is much thinner along the two shorter sides to increase the bandwidth [4]-[5].

The first step is to determine the dimensions of the bed of nails to cover the required frequency band [5]. A unit element with periodic boundaries is used for accurate calculation of the stop band of the periodic electromagnetic band gap structure. The height of the pin surface is around $\lambda_0/4$ at the center frequency of 75 GHz.Although the width pin and the gap between the pins affect the stopband band of the flange, it can be adjusted by changing the pin height and thickness of the air gap between the AMC and PEC. The bandwidth increases as the gap between the two surfaces decreases. The stopband moves toward lower frequencies if the height of the pin increases in an inverse relationship [4]. Electromagnetic wave simulation software, CST Studio, is used for the simulation. The dispersion diagram shown in Fig. 2 shows the unit elements with an air gap g of 3 mills, the bed of nails height d_f

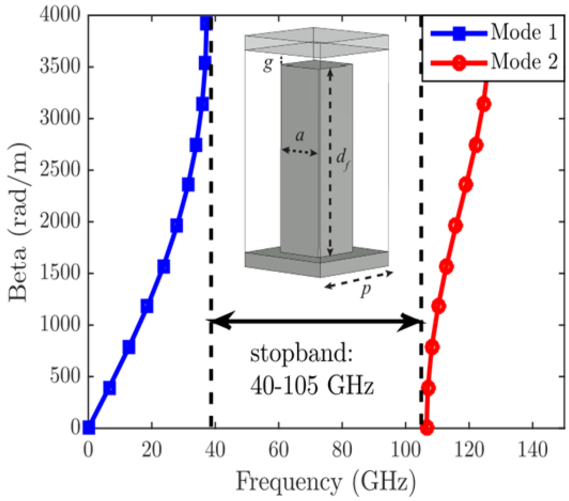


Fig. 2. Dispersion diagram for the infinite periodic pin unit cell.

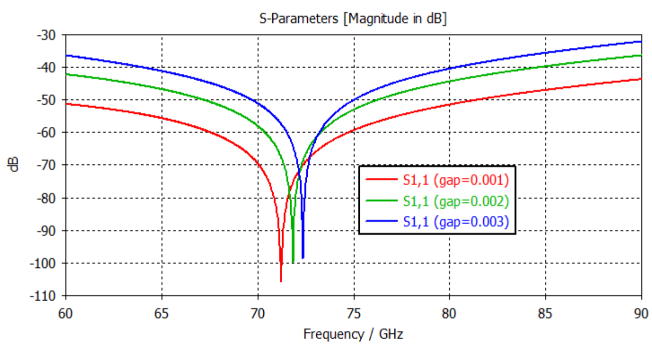


Fig. 3. Simulated S11 for different gap sizes.

as 35 mills, the width of the pin surface *a* as 15mills, and the pitch *p* as 25 mills. The stopband covers frequencies from 40 to 105 GHz, including the entire E-band.

Unlike previous designs [7]-[11], the current design combines the principles of operation of the choke flange design [6] and gap waveguide technology. The two rows of pins used are circular in nature to ease the mechanical design and fabrication of the pins. The pin surface forms an AMC surface that creates a parallel-plate cut-off within the band at the interconnects between waveguide flange surfaces, and in this way reduces loss and reflection. The present E-band gap adapter design has a fixed air gap of 3 mils, although smaller gaps can be used as well for even better performance as shown in Fig. 3.

B. Mechanical Design

The rim around the waveguide opening has the same height as the pins and its short walls are 14 mils thick while its long walls are 45 mils thick along the longer dimension of the waveguide opening. Another rim of 47 mils is added around the pin surface. This external rim provides protection to prevent the pin surface from breaking. Guide pins are also included to ensure proper alignment between the contactless waveguide flange and the conventional flange in adherence to standard flange definitions.

Fig. 4. Front face of the contactless flange.

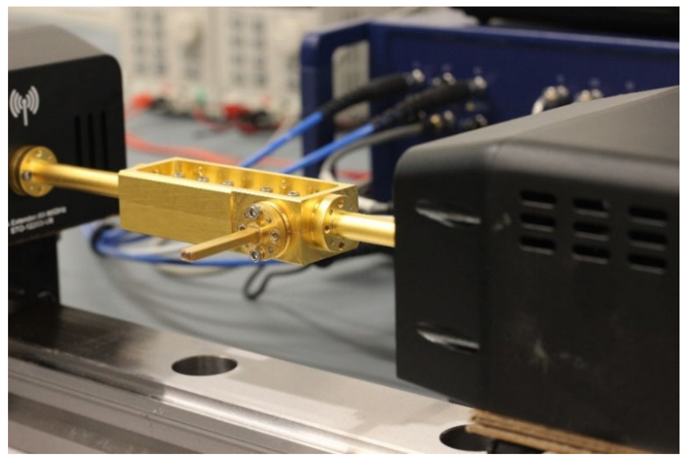
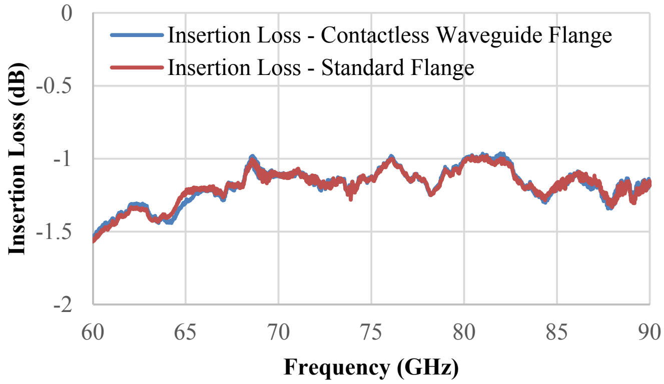


Fig. 5. VNA extenders mounted on the rails.

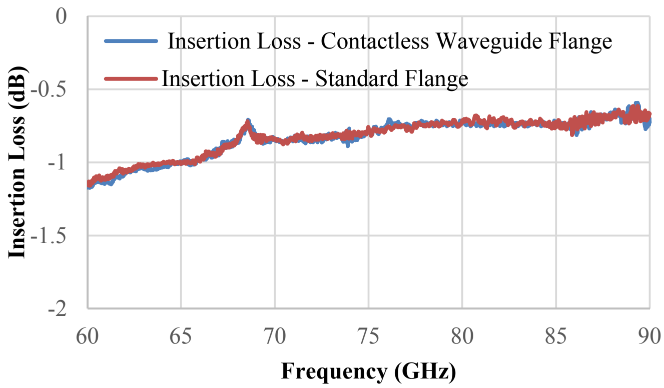
By eliminating the need for screws, measurements can be performed considerably faster since the flanges only need to be aligned and pushed together into place.

III. Results

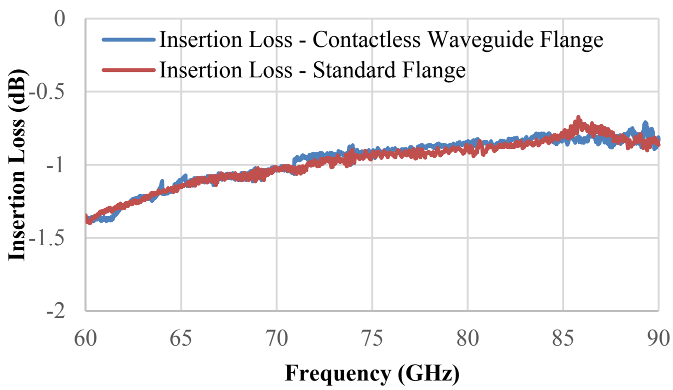
The contactless flange was incorporated into E-band extenders which were mounted on the rails as shown in Fig. 5 to realize fast measurements. Using rails allows faster measurements as the DUT can be quickly put in place and removed and there is a possibility of automating the measurements especially when conducting repeatable measurements. The WR-12 contactless waveguide flange was used to measure the insertion loss of an E-band filter and two different E-band directional couplers. The results were then compared with the results derived from measurements using the conventional flange as shown in figure 6 (a), (b) and (c). The results show minimal difference (less than 0.1 dB) between the two setups. This ascertains using the CWF could be used to achieve reliable measurements. The insertion loss measurement was repeated five times and the results were the same in all instances.



(a)



(b)



(c)

Fig. 6. (a) Measured Insertion Loss for E-band filter. (b) Measured Insertion Loss for the first coupler. (C) Measured Insertion Loss for the second coupler.

IV. Conclusion

This paper demonstrated how to design and realize the contactless waveguide flange (CWF). Simulation results showed a return loss below -40 dB across the whole band for a 1 mill gap. An E-band contactless flange has been presented and it was demonstrated by using the contactless flange with extenders mounted on rails. It showed that faster, accurate and reliable repeatable measurements can be achieved as presented in the previous section.

Acknowledgment

The authors wish to acknowledge their colleagues, Mr. Fang Lu and Ms. Nina Kang for helping and reviewing of the manuscript.

References

[1] A. R. Kerr, “Mismatch caused by waveguide tolerances, corner radii, and flange misalignment,” *Nat. Radio Astronomy Observatory*, Charlottesville, VA, USA, Tech. Rep. Electronics

[2] Division Technical Note No. 215, 2010. [Online]. Available: https://library.nrao.edu/public/memos/edtn/EDTN_215.pdf

[3] P.-S. Kildal, "Three metamaterial-based gap waveguides between parallel metal plates for mm/submm waves", 3rd European Conference on Antennas and Propagation, 2009. *EuCAP 2009*. Berlin, Germany, 2327 March 2009.

[4] E. Rajo-Iglesias and P.-S. Kildal, “Numerical studies of bandwidth of parallel-plate cut-off realised by a bed of nails, corrugations and mushroom-type electromagnetic bandgap for use in gap waveguides,”

[5] E. Pucci and P.-S. Kildal, “Contactless non-leaking waveguide flange realized by bed of nails for millimeter wave applications,” *in Proc. 6th Eur. Conf. Antennas Propag. (EUCAP)*, May 2012, pp. 3533–3536

[6] R. Naruse, H. Saito, J. Hirokawa, and M. Zhang, “Non-contact wavefeed with choke-flange waveguide at the development section of the expansion antenna for small satellite,” *IEICE, Tokyo, Japan*, vol. 114, no. 194, pp. 77–82, Tech. Rep. SANE 2014-61, Aug. 2014.

[7] Xiang Chen, Wanzhao Cui, etc. “Low Passive-Intermodulation Contactless Waveguide Adapter Based on Gap Waveguide Technology,” *13th Eur. Antennas Propag. Conf.*, 2019.

[8] P.-S. Kildal, E. Alfonso, A. Valero-Nogueira, and E. Rajo-Iglesias, “Local metamaterial-based waveguides in gaps between parallel metal plates*,” IEEE Antennas Wireless Propag. Lett.*, vol. 8, pp. 84–87, Apr. 2009

[9] H. Li, A. Arsenovic, J. L. Hesler, A. R. Kerr, and R. M. Weikle, “Repeatability and mismatch of waveguide flanges in the 500–750 GHz band,” *IEEE Trans. Terahertz Sci. Technol*., vol. 4, no. 1, pp. 39–48, Jan. 2014.

[10] Dongquan Sun, Zhenhua Chen, and Jinping Xu. “Flexible rectangular waveguide based on cylindrical contactless flange,” *Electron Lett*., vol. 52, no. 25, pp. 2042-2044, Dec 2016.

[11] Dongquan Sun and Jinping Xu. “Real Time Rotatable Waveguide Twist Using Contactless Stacked Air-Gapped Waveguides,” *Microw. Wirel. Compon. Lett*. vol. 27, no. 3, pp215-217, March 2017.